

Hildebrandt, Kurt

From: Hildebrandt, Kurt
Sent: Wednesday, April 01, 2015 1:51 PM
To: Ryan A. Hoffman; Stan Belieu; Bill Sydow; Larry Pierce; Chris Vierrether
Cc: Mary Mindrup; David Garrett; Meissner, Benjamin
Subject: Scientists Pressured Over Link Between Wastewater Injection, Quakes, E-mails Show

FYI – Some pretty interesting discussion.

Scientists Pressured Over Link Between Wastewater Injection, Quakes, E-mails Show

By *Benjamin Elgin* and *Matthew Philips* BNA

March 31 — Energy firms tried to slow science inquiries blaming them for earthquakes in Oklahoma, e-mails obtained by Bloomberg and other media outlets suggest.

Austin Holland, Oklahoma's state seismologist, got a request in November 2013 that made him nervous. It was from David Boren, president of the University of Oklahoma, which houses the Oklahoma Geological Survey where Holland works.

Boren, a former U.S. senator, asked Holland to his office for coffee with Harold Hamm, the billionaire founder of Continental Resources, one of Oklahoma's largest oil and gas operators. Boren sits on the board of Continental, and Hamm is a donor to the university, giving \$20 million in 2011 for a new diabetes center. Says Holland: "It was just a little bit intimidating."

Holland had been studying possible links between a rise in seismic activity in Oklahoma and the rapid increase in oil and gas production, the state's largest industry. During the meeting, Hamm requested that Holland be careful when publicly discussing the possible connection between oil and gas operations and a big jump in the number of earthquakes, which geological researchers were increasingly tying to the underground disposal of oil and gas wastewater, a byproduct of the fracking boom that Continental has helped pioneer.

"It was an expression of concern," Holland recalls.

Meeting Details Emerge in E-Mails

Details surrounding that meeting and others have emerged in recent weeks as e-mails from the Oklahoma Geological Survey have been released through public records requests filed by Bloomberg and other media outlets, including EnergyWire, which first reported the Hamm meeting.

The e-mails suggest a steady stream of industry pressure on scientists at the state office. But oil companies say there's nothing wrong with contact between executives and scientists.

"The insinuation that there was something untoward that occurred in those meetings is both offensive and inaccurate," says Continental Resources spokeswoman Kristin Thomas. "Upon its founding, the Oklahoma Geological Survey had a solid reputation of an agency that was accessible and of service to the community and industry in Oklahoma. We hope that the agency can continue the legacy to provide this service."

Likewise, Boren says such conversations are harmless.

Boren Says Meeting 'Informational.'

"The meeting with Harold Hamm was purely informational," the university president said in a statement on March 27. "Mr. Hamm is a very reputable producer and wanted to know if Mr. Holland had found any information which might be helpful to producers in adopting best practices that would help prevent any possible connection between drilling and seismic events. In addition, he wanted to make sure that the Survey (OGS) had the benefit of research by Continental geologists."

Boren is on the board of The Bloomberg Family Foundation, founded by Michael Bloomberg, the owner of Bloomberg LP.

Before Holland became the state seismologist in 2010, there wasn't much for Big Oil and state researchers to argue about. Over the previous 30 years, Oklahoma had averaged fewer than two earthquakes a year of at least 3.0 in magnitude. In 2015 the state is on pace for 875, according to Holland.

Oklahoma passed California last year as the most seismically active state in the continental U.S. One significant change in drilling practices is contemporaneous with the increase in seismic activity: horizontal hydraulic fracturing. Fracking has been around for decades, but technological advances have allowed companies to drill sideways, injecting a high-pressure mix of water, mud, and sand into shale formations deep underground, creating access to previously unreachable pockets of oil and gas.

Oklahoma Oil Production Doubles

Oil production in Oklahoma has more than doubled over the past decade, creating new wealth for the state as well as an unwanted surplus. Horizontal wells can produce as much as nine or 10 barrels of salty, toxin-laced water for every barrel of oil. Much of that fluid is injected back underground into wastewater disposal wells. It's this water, injected near faults, that many seismologists—including those at the U.S. Geological Survey—say has caused the spike in earthquakes.

The Hamm and Boren meeting wasn't the only such informational session. In an e-mail from October 2013, Holland updated his superiors on a meeting he had in the office of Patrice Douglas, then one of the three elected members of the Oklahoma Corporation Commission, which regulates that state's oil and gas companies. Also at the meeting was Jack Stark, then-senior vice president for exploration at Continental and now its president.

“The basic jist [sic] of the meeting is that Continental does not feel induced seismicity is an issue and they are nervous about any dialog about the subject,” wrote Holland. He also wrote that Continental and Douglas were concerned about his participation in a joint statement he'd recently signed with the U.S. Geological Survey suggesting a link between quakes and the oil industry.

As Oklahoma has become the capital of American seismic activity, scientists, citizens, and some state lawmakers have been critical of state officials for their perceived slowness in drawing a connection between earthquakes and oil and gas activities, which account for 1 in 5 jobs in the state. Over the past couple years, as research began to get published and many seismologists became convinced that earthquakes were being induced by wastewater disposal, the OGS remained on the fence. In early 2013 the academic journal *Geology* accepted a paper attributing a 5.6 magnitude quake that hit Oklahoma in 2011 to underground changes resulting from wastewater disposal wells. In March 2013, OGS put out its own statement, attributing the quake to “natural causes.”

And in February 2014, three months after Holland's meeting with Hamm, the agency released a statement playing down the role of industry, saying the “majority, but not all, of the recent earthquakes appear to be the result of natural stresses.”

Conflict of Interest, Critics Say

“This is a conflict of interest that we never before could've imagined,” says Jason Murphey, a Republican state representative from Logan County, which has been one of the most seismically active areas in the state over the past year. “When Boren facilitates that meeting, it sends a message to Austin Holland.”

Even when earthquakes appeared strongly correlated to wastewater injection, OGS has been reluctant to discuss a connection. In September 2013 a new disposal well was turned on in Love County in southern Oklahoma. Soon, quakes began to jolt the area, sometimes several a day.

The well reached its peak daily injection of more than 9,000 barrels of wastewater on Sept. 20, 2013. Three days later the area experienced a magnitude 3.4 quake, moving furniture inside homes and knocking down a chimney. Injection at the well was curtailed, then stopped altogether. The seismic activity dipped almost immediately.

Still, the OGS hesitated to link the two.

“We cannot rule out that this observation could be simply a coincidence,” Holland wrote in a report a week later. In early October, Holland spoke at a town hall meeting in Love County, where he again said no conclusions could be drawn about the cause of the quakes.

Many residents were frustrated by the lack of answers. But ExxonMobil geologist Michael Sweatt wrote in an e-mail to Holland: “I would like to congratulate you on a job well done at the Town Hall meeting in Love County. I believe you delivered an unbiased report on the recent earthquake activity and answered the residents' questions the best you could.”

Today, as the number of earthquakes continues to soar, Holland has evolved in his position. He recently told Bloomberg that the vast majority of the increase in earthquakes is due to the injection of oil and gas wastewater. Yet he bristles at any suggestion that industry pressure slowed him from reaching that conclusion. Oklahoma has naturally occurring earthquakes, he says, and there have been large spikes of natural earthquakes in the past where no oil and gas development was occurring. It was proper, Holland says, to start with the hypothesis that the quakes were not man-made.

“Science doesn't operate in beliefs,” he says. “It operates in demonstrable facts.”

Hildebrandt, Kurt

From: Hildebrandt, Kurt
Sent: Thursday, April 02, 2015 9:08 AM
To: Ryan A. Hoffman; Mike Cochran
Cc: Larry Pierce; chris vierrether; Stan Belieu; Bill Sydow
Subject: FW: Kan. links quakes to oil and gas, sharply limits waste disposal

FYI – Article from E&E on the KCC Order

Kan. links quakes to oil and gas, sharply limits waste disposal

Mike Soraghan, E&E reporter

BLUFF CITY, Kan. -- Regulators in Kansas have imposed sharp restrictions on oil and gas activity in two southern counties in response to increased earthquakes in the area.

The Kansas Corporation Commission (KCC) cited an "immediate danger" to public safety as the reason for limiting the pressure that can be used to inject wastewater into disposal wells and the volumes that can be injected.

"Because individual earthquakes cannot be linked to individual injection wells, this order reduces injection volumes in areas experiencing increased seismic activity," commission officials stated in the March 19 [order](#). "The Commission finds damage may result if immediate action is not taken."

Kansas' move is a contrast with neighboring Oklahoma, where officials dealing with the same problem just across the border are focusing on finding wells drilled too deep ([EnergyWire](#), March 26). The Oklahoma Corporation Commission (OCC) has not limited injection volumes or pressures but has not ruled out doing so in the future.

"We may very well get to that point," Tim Baker, director of OCC's Oil and Gas Conservation Commission, said last week at a forum in Medford, Okla. ([EnergyWire](#), March 26).

The Oklahoma commission has also avoided explicitly linking earthquakes to disposal wells, saying getting embroiled in such a debate could bog down its response. But Kansas officials made a direct correlation.

"The increased number of recorded earthquakes in Kansas coincides with an increase in the number of injection wells and the amounts of injected saltwater in Harper and Sumner counties," the order states.

Kansas had 127 earthquakes last year, according to the commission order, and more than 50 this year by mid-March. From 1981 to 2010, Kansas had 31 quakes.

In 2010, the two counties had 97 injection wells that injected 800 million gallons of fluid. In 2013, according to the order, that rose to 150 wells injecting 2.6 billion barrels.

Oklahoma City-based SandRidge Energy Inc. is the major operator in the area, producing from the Mississippi Lime play. The formation is known to produce high amounts of wastewater compared with conventional production. A SandRidge spokesman said the company intends to comply with the order but declined to discuss its plans, such as whether it will appeal the order.

Under the order, no wells injecting into the Arbuckle Formation in Harper and Sumner counties can inject more than 25,000 barrels (about 1 million gallons) a day. That places limits on at least 23 wells in the area that had been granted permits to inject 30,000 barrels or more a day.

Beyond that, in four areas within those counties, wells will be limited to 8,000 barrels (336,000 gallons) a day and pressure of 250 pounds per square inch within 100 days of the order, which ratchets down the volume across that 100-day period.

Kansas officials are also requiring companies to show they have not drilled deeper than the Arbuckle Formation. Beneath the Arbuckle in most places is "basement" rock. Oil and gas officials say that injecting into basement rock creates a greater risk of causing earthquakes than injecting into shallower layers.

Injection-well opposition

The order was issued hours after a hearing on two SandRidge injection wells that were protested by Frank Smith, who lives on a farm in the Bluff City area. SandRidge wants to use the wells for enhanced oil recovery, which is different from disposal.

In an interview last week, Smith said that his home has been hit by earthquakes, as have many of his neighbors' homes.

"They're hurting a lot of people," Smith said of oil companies and their wells. "They're doing incremental damage to so many homes."

At the hearing, SandRidge officials sought to prevent Smith from bringing up connections between injection wells and earthquakes. But commissioners ruled that Smith could bring up the topic.

A corporation commission spokesman said the agency wouldn't comment beyond the language of the order, because companies might appeal it. But Smith said he believes the commissioners used the opportunity presented by his protest to issue the order. Smith's protest of the two wells is still under consideration by the commission.

Of the 72 large-volume injection wells in Harper and Sumner counties identified in the order, 44 are owned by SandRidge, the dominant producer in the Mississippi Lime play. SandRidge also has the highest injection volumes.

Another 14 are owned by Tapstone Energy, an Oklahoma City-based company founded by former SandRidge CEO Tom Ward.

One is owned by Chesapeake Energy Corp. of Oklahoma City and seven are owned by Source Energy of Highlands Ranch, Colo., which says it has more than 350,000 acres of oil and gas rights on the Kansas side of the Mississippi Lime play.

Efficient disposal is key to SandRidge's operations. Company officials said in a recent securities filing that a policy requiring the company to shut down a "substantial number" of its wells "could materially and adversely affect the Company's business, financial condition and results of operations" ([EnergyWire](#), March 9).

The companies and others with an interest have 30 days from the date of the order to request a hearing. So far, none has.

Hildebrandt, Kurt

From: Hildebrandt, Kurt
Sent: Thursday, April 09, 2015 11:24 AM
To: Ryan A. Hoffman; 'rex@kgs.ku.edu'; Mike Cochran
Cc: Mindrup, Mary
Subject: Kansas Seismicity Discussion

Ryan, Rex & Mike -

As you know, EPA is in the process of reviewing a permit application from Berexco/KGS for a pilot geologic sequestration (GS) project located near Wellington in Sumner County, Kansas. With the increase in seismic events that have been occurring in Kansas over the last couple of years and the recent order from KCC limiting injection rates in Harper and Sumner counties, I'd like to get EPA, KCC, KDHE & KGS together to talk about what the Kansas Seismicity Task Force has found for those two counties but in particular Sumner County; the KCC order and the requirements for Class 2 wells in Harper and Sumner Counties which are disposing into the Arbuckle, and; any conditions that KDHE is considering placing on the Arbuckle disposal wells which they oversee. The purpose of this meeting would be to help inform EPA on these topics and determine what impacts they might have on the Wellington GS project and any permit that EPA might issue.

Because KGS is an active participant in the GS permit application that EPA is reviewing, I'd like to limit the KGS participation in this meeting to just those from KGS who are involved in the Seismicity Task force. I do plan on having a follow-up meeting on this topic that would involve all of the parties from this meeting along with Berexco and the KGS team who are part of the GS project to discuss this topic further but believe that it would be best to not involve anyone who is part of the permit application during the initial discussions.

Given that much of the information more than likely resides within KGS, I'd propose holding the meeting at the KGS offices in Lawrence or alternatively in Wichita at the KCC offices. If you could let me know if you would be willing to participate in the meeting, where you think it would be best to hold it and possible dates in April or May (with the exception of the week of May 4th) that you would be available for the meeting, I'd appreciate it.

Thanks for your time and I look forward to hearing back from each of you. Please feel free to get in touch with me if you have any questions about the proposed meeting or topics.

Regards,
Kurt

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Hildebrandt, Kurt

From: Hildebrandt, Kurt
Sent: Tuesday, April 21, 2015 11:04 AM
To: 'Mike Cochran'; 'Ryan A. Hoffman'; 'Rex Buchanan'
Subject: FW: Big development in Oklahoma on quakes - WOW

FYI – I'm sure you are already aware of this development but just in case it hadn't made it your way yet.

From: Dellinger, Philip
Sent: Tuesday, April 21, 2015 10:33 AM
To: R6 6WQ-SG; Brown, Jamesr
Subject: Big development in Oklahoma on quakes

OGS acknowledges widespread induced seis.

http://wichita.ogs.ou.edu/documents/OGS_Statement-Earthquakes-4-21-15.pdf

Hildebrandt, Kurt

From: Hildebrandt, Kurt
Sent: Tuesday, April 21, 2015 1:09 PM
To: 'Mike Cochran'; 'Rex Buchanan'; 'Ryan A. Hoffman'
Subject: Azle earthquakes likely caused by oil and gas operations, study says

Meanwhile, in Texas....

<http://www.usnews.com/news/science/news/articles/2015/04/21/study-links-swarm-of-quakes-in-texas-to-natural-gas-drilling>

From: Dellinger, Philip
Sent: Tuesday, April 21, 2015 12:02 PM
To:
Subject: FW: DMN: Azle earthquakes likely caused by oil and gas operations, study says

FYI

Azle earthquakes likely caused by oil and gas operations, study says

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Tom Fox/Staff Photographer

A pickup passes a ranch entrance outside of Reno in rural Parker County. Oil and gas operations are the most likely cause of dozens of earthquakes that began rattling the North Texas towns of Azle and Reno in November 2013, a group of SMU scientists says.

By ANNA KUCHMENT akuchment@dallasnews.com

Staff Writer

Published: 21 April 2015 10:00 AM

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Related

- Read the full study published in 'Nature Communications'
- Rawlings now 'even more anxious' to get Dallas, Irving study
- Photos: SMU-led research points to likely cause of quakes
- FAQ: Unraveling the mystery around North Texas quakes
- More North Texas earthquakes coverage

Oil and gas operations are the most likely cause of dozens of earthquakes that began rattling the North Texas towns of Azle and Reno in November 2013, a group of scientists has concluded.

The study, led by researchers at SMU and published Tuesday in the journal *Nature Communications*, presents some of the most conclusive evidence yet that humans are shifting faults below Dallas-Fort Worth that have not budged in hundreds of millions of years.

While experts have not yet determined what's causing the shaking in Dallas and Irving, the new paper previews aspects of that study and includes suggestions that will help speed research.

"It's certainly one of the best cases in the literature," said Art McGarr of the U.S. Geological Survey's Earthquake Hazards Program in Menlo Park, Calif.

The new findings contradict statements by the Railroad Commission of Texas that there are no definitive links between oil and gas activity and earthquakes in the state.

Shown an embargoed version of the paper, the commission's staff seismologist Craig Pearson wrote in a statement that "the study raises many questions with regard to its methodology, the information used and conclusions it reaches." But he declined to answer specific questions before meeting with the paper's authors. The Railroad Commission regulates the oil and gas industry.

The Azle study is the result of a yearlong collaboration involving 11 researchers at SMU, the University of Texas at Austin, and the U.S. Geological Survey and was reviewed by independent experts before publication.

The scientists zeroed in on an unusual mechanism behind the quakes: workers pushing liquid into the ground on one side of a fault and sucking gas and groundwater from the other side of the fault.

"The combination of these activities seems to have triggered the earthquakes, and that was a real surprise to us," said Matthew Hornbach, a geophysicist at SMU and a lead author of the paper.

Injecting fluids into the ground or extracting them has long been known to cause quakes, but rarely — if ever — have the two been caught acting in concert.

The geology of each region is unique, however, so these mechanisms may not be at work elsewhere.

The findings come at a time of heightened debate over oil and gas regulations in Texas. The state Legislature is considering bills that would curtail local governments' ability to impose fracking bans. Lawmakers are also weighing proposals for increased earthquake research and monitoring.

The paper's authors call for additional measures: closer monitoring of oil and gas wells and improved access to geologic information held by oil and gas companies.

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Wells still in operation

The Azle and Reno earthquakes culminated in two magnitude 3.6 tremors in November and December 2013 but have since dissipated, said Heather DeShon, an SMU seismologist who co-led the new study.

All four wells continue to operate, though both wastewater wells have reduced the volume of liquid they pump into the ground, according to Railroad Commission records last updated in September 2014.

The earthquakes mark the third set of North Texas tremors to be linked with oil and gas activity.

In 2008 and 2009, dozens of small tremors struck near Dallas/Fort Worth International Airport; in 2009 and 2010, more than 50 quakes shook Cleburne. Researchers are still investigating the cause of the recent, widely felt earthquakes in Irving and Dallas.

Before 2008, North Texas had experienced only two recorded earthquakes, both believed to be natural; the Azle and Reno area had experienced none. Since then, North Texas has logged more than 150 quakes of significant magnitude. The uptick is part of a dramatic increase in seismicity in central U.S. states, including Texas, Oklahoma, Arkansas, Colorado and Ohio.

The U.S. Geological Survey has blamed the rising rates largely on wastewater wells. The agency is expected to issue a report this week warning of a heightened hazard from earthquakes in Texas and other central states.

The Azle study is one of the most in-depth investigations of a Texas earthquake swarm. While earlier reports have linked quakes with wastewater wells based largely on timing and proximity, Hornbach and his colleagues sought to gain a clearer understanding of what was happening along the faults.

From previous studies, they knew it would take only a tiny amount of pressure to activate the faults, which are already stressed from the natural movement of tectonic plates.

“You’re just talking about kicking a system into motion,” said DeShon.

Ruling out drought

Still, they were able to rule out several causes for the quakes, including drought. They concluded that a 7-foot drop in water levels at nearby Eagle Mountain Lake translated to pressure changes below ground that were far too weak to affect the faults, which lie between 1 and 5 miles underground.

The seismologists also discounted natural shifts in tectonic plates as possible earthquake triggers. The two faults they mapped in Reno do not reach the surface, which suggests the faults have been dormant for more than 300 million years.

Still, they couldn't completely rule out that this was a randomly occurring swarm and wrote that it was "possible, but unlikely" that the earthquakes were natural in origin.

The team then gathered data on area wells, and here they found a smoking gun.

After analyzing data provided by the Railroad Commission and oil and gas companies, the scientists found that two wastewater wells near the site were generating the highest pressures close to the faults.

One, operated by XTO, a subsidiary of ExxonMobil, is located within about one mile of the earthquake epicenters, according to a locator map included in the study. Workers injected around 508 million gallons of wastewater into it from June 2009, when it opened, through September 2013, just before the earthquakes started. That's the equivalent of 890 Olympic-sized swimming pools.

The other well, operated by EnerVest, is located about 2 miles from tremor epicenters and buried around 123 million gallons of fluid from October 2010 through September 2013.

The team also found that two gas wells located almost directly above the earthquake swarm brought to the surface large volumes of groundwater, which further destabilized the surrounding rocks.

The underground pressure changes associated with the wells were tens to hundreds of times larger than those associated with the effects of the drought.

When Hornbach and his colleagues estimated how pressure from the wells built up along the faults from 2009 to 2013, they found that the buildup synced with the timing of the quakes.

Future prognosis

Will earthquakes return to Azle and Reno?

"That's the big question," said Brian Stump, an SMU seismologist who co-authored the study.

McGarr of the USGS, who was not involved in the research, said that the longer wastewater injections continue unabated, the greater the likelihood that earthquakes will spread across a wider area and grow stronger.

Cliff Frohlich, a seismologist at UT-Austin who is a co-author of the Azle study, said nothing in North Texas' history points to a risk of damaging quakes, though he can't rule them out.

“The kinds of quakes you’ve been having up there are not serious, and I would be very surprised if a quake greater than magnitude 4 would occur,” he said.

In the paper, the scientists call for several measures that would lower the risk of man-made quakes. “We want to try to be more proactive, rather than reactive,” said Hornbach.

One suggestion is improved information sharing among regulators, researchers and oil and gas companies.

More data needed

Companies such as Exxon and XTO readily provided the scientists with information they requested, including fault locations, but the process could be faster and more efficient, according to the scientists.

“We’re lucky that companies have been willing to work with us,” said Hornbach. “They have gone far above the call of duty. But we frankly still need a lot more data, and there are currently no regulations that require that data to be easily accessible.”

Detecting small earthquakes that might herald larger ones is another approach that the scientists recommend.

Texas currently has 16 permanent seismic stations that can record earthquakes down to a magnitude of 3, which experts say is not nearly sensitive enough. The denser the network, the greater its level of precision.

Texas does have a seismic network in the works. Legislation on the table in Austin would provide \$2.5 million in funding for TexNet, which includes an additional 22 permanent seismic monitors, plus 36 portable stations that could be deployed to areas experiencing new tremors.

Stump calls TexNet 'a good start' but adds that it's still unclear how many of those stations would end up in North Texas and whether the funding would provide for additional manpower to read and interpret the new quake data.

Detecting quakes down to a magnitude of 2 is important because small quakes can help predict larger ones and, if the tremors are man-made, they can alert regulators and oil and gas companies to the need to slow or suspend wastewater injections.

Finally, the authors recommend that companies be required to regularly report how much groundwater their oil and gas wells bring to the surface. As the Azle study shows, removing water from the earth can be as troublesome as injecting it.

Follow Anna Kuchment on Twitter at @akuchment.

MISSED WARNINGS

Scientists have understood for decades that injecting wastewater into the ground at high pressures can cause earthquakes. They have also known that monitoring the underground pressure near injection sites could reduce the risk of quakes. Some signs:

1962-1981: Rocky Mountain Arsenal in Colorado. The disposal of hazardous waste from this defense plant into a deep well causes earthquakes that continue for years after injections stop.

1968: Dallas. In a volume published by the American Association of Petroleum Geologists, a Dallas-based oil consultant writes that it's essential to closely observe pressures near injection wells.

1969-1973: Rangely Oil Field in Colorado. Inspired by the Rocky Mountain Arsenal example, the U.S. Geological Survey launches an experiment to show how man-made quakes can be controlled. The agency finds that, if workers monitor the pressure near injection wells and adjust the rate and volume of injections accordingly, they can better manage earthquake risk.

2014: Oklahoma. A study in the journal *Science* links a sharp increase in Oklahoma earthquakes to "massive wastewater injection." The author, Cornell University's Katie Keranen, writes that regular measurement of subsurface pressure could provide an early warning about earthquake risk but notes that such data "are rarely accessible."

2014: Austin. In public comments to the Railroad Commission on its proposed rules for disposal wells, researchers from Southern Methodist University recommend that the commission require companies to measure and report subsurface pressures near injection wells annually. The commission replies that the change is not warranted.

2015: Azle and Reno, Texas. Scientists find that elevated underground pressure near wastewater wells probably caused a series of earthquakes near Fort Worth.

SOURCE: *Dallas Morning News* research

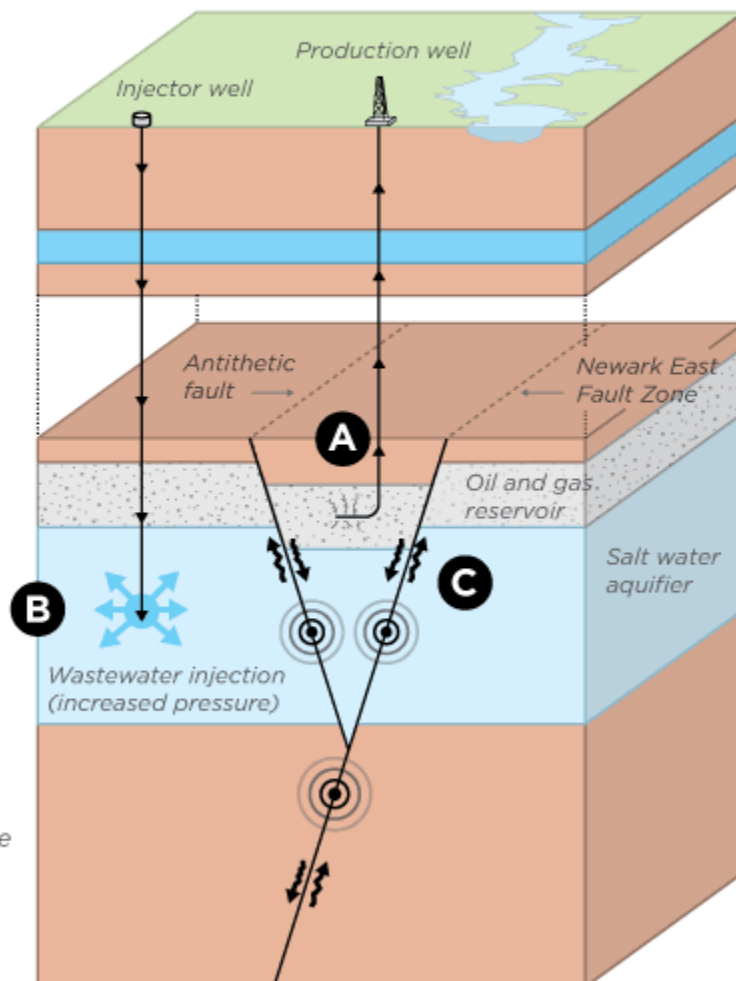
A perfect combination

Scientists believe that four wells were the primary cause of the earthquakes in Azle and Reno. Two are wastewater injection wells, where companies dispose of water, chemicals and sand used in hydraulic fracturing; and two are natural gas wells.

A. Workers extract gas and salt water from a production well, causing a decrease in underground pressure.

B. On the other side of the fault, workers at a different well inject wastewater into the ground, causing an overall pressure increase.

C. The pressure changes cause nearby faults to slip, triggering earthquakes.



SOURCE: Hornbach et al., Nature Communications 2015

Troy Oxford/Staff Artist

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